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MEDICAL X-RAY PROTECTION UP TO TWO MILLION VOLTS

Handbook 41

U. S. Department of Commerce
National Bureau of Standards

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U. S. Department of Commerce — Charles Sawyer, Secretary
National Bureau of Standards — E. U. Condon, Director

Medical X-Ray Protection up to Two Million Volts

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Preface

This Handbook is to supersede the National Bureau of Standards Handbook 20, entitled "X-ray Protection," prepared by the Advisory Committee on X-ray and Radium Protection, and last revised in 1936.

These recommendations are intended primarily for the protection of the radiation worker and not for the patient. However, with the increasing use of radiation and of materials emitting radiation, it is necessary for the medical profession to exercise great caution and restraint in the use of X-rays for diagnosis and the treatment of nonmalignant diseases. Current methods and practices should be reviewed to see whether the same result could be obtained with less radiation. In particular, the beam of radiation reaching the patient should be as small in cross section as is essential for the examination—especially in fluoroscopy. The gonads should be protected whenever possible either by limiting the size of the beam or by local shielding.

Dermatologists and radiologists should avoid as much as possible the use of radiation in the treatment of benign conditions of the hands, such as fungus infections, in the case of people handling radioactive materials or otherwise being occupationally exposed to radiation. It should be the duty of the physician to ascertain whether the patient is occupationally exposed to radiation before prescribing radiation treatment. It should be the duty of the patient to tell the physician that he is occupationally exposed to radiation, whenever the physician prescribes radiation treatment.

For purposes of this Handbook the permissible dosage rate is taken as 0.300 roentgen per week. This is in accord with the recent recommendations of Subcommittee No. 1. All barrier thicknesses given in this Handbook are based on the assumption that the 0.300 roentgen per week is obtained by a constant dosage rate throughout a 48-hour week. If future data indicate that the permissible dose should be changed, the tables of barrier and distance requirements will require modification. The curves may be used, however, to obtain corrected barrier requirements.

As indicated in sections 12.2c and 12.2d, the information required for most economical designs of X-ray installations are not yet available. Certain approximations are suggested until these data are available.

The Advisory Committee on X-ray and Radium Protection was formed under the sponsorship of the National Bureau of Standards and with the cooperation of the leading radiological organizations upon the recommendation of the International Commission for Radiological Protection. This Committee, although small in size, has functioned effectively. However, the advent of atomic energy has introduced a large number of new and serious problems in the field of radiation protection.

At a meeting of the Advisory Committee in December 1946, the representatives of the various participating organizations agreed that the problems in radiation protection had become so manifold that the Committee should enlarge its scope and membership, and should appropriately change its title to be more inclusive. Accordingly, at that time the name of the Committee was changed to the National Committee on Radiation Protection. At the same time the number of participating organizations was increased and the total membership considerably enlarged. In order to distribute the work load, seven working subcommittees were established as noted below. Each of these committees is charged with the responsibility of preparing protection recommendations in its particular field. The reports of the subcommittees are approved by the main committee before promulgation.

The following individuals representing the organizations indicated, compose the main committee:

H. L. ANDREWS and E. G. WILLIAMS, M. D., U. S. Public Health Service.
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The following are the subcommittees:

Subcommittee 1. Permissible External Dose, G. Failla, chairman.
Subcommittee 2. Permissible Internal Dose, K. Z. Morgan, chairman.
Subcommittee 3. X-rays up to Two-Million Volts, H. O. Wyckoff, chairman.
Subcommittee 4. Heavy Particles (Neutrons, Protons, and Heavier), Dean Cowie, chairman.
Subcommittee 5. Electrons, Gamma Rays, and X-rays Above Two-Million Volts, L. Marinelli, chairman.
Subcommittee 6. The Handling and Disposal of Radioactive Isotopes and Fission Products, H. M. Parker, chairman.
Subcommittee 7. Monitoring Methods and Instruments, H. L. Andrews, acting chairman.

The present Handbook has been prepared by Subcommittee 3, made up as follows: H. O. Wyckoff, chairman; C. B. Braestrup, L. L. Call, E. E. Charlton, A. C. Cipolaro, M. D., M. Friedman, M. D., Russell Morgan, M. D., R. R. Newell, M. D., E. W. Philleo, Scott W. Smith, John Trump, and J. L. Weatherwax.

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CONTENTS

Page
Preface III
I. General 1
  1. Definitions 1
  2. Survey and inspection 4
  3. Working conditions 6
  4. Structural details of protective barriers 9
  5. Plans for an X-ray installation 10
II. Rules for specific applications 11
  6. Fluoroscopic X-ray installations for potentials up to 100-kilovolts peak 11
  7. Radiographic installations for potentials up to 100-kilovolts peak 13
  8. Dental roentgen installations operated at potentials up to 70-kilovolts peak 16
  9. Special requirements for mobile diagnostic equipment operating at potentials up to 100-kilovolts peak 17
  10. Fluorographic equipment operating at potentials up to 100-kilovolts peak 17
  11. Therapeutic X-ray installations operated at potentials up to 250 kilovolts 28
  12. Therapeutic X-ray installations energized by potentials of 251 to 2,000 kilovolts 22
III. Electrical Protection 24
  13. General 24
  14. Protection from high-voltage circuits 28
  15. Grounding 30
  16. Warnings and instructions 30
  17. First-aid and fire-extinguishing devices 31
  18. Inspection and maintenance 31
IV. Appendix 32
  19. Radiation attenuation curves 32
  20. Approximate lead thicknesses required to reduce radiation dosage rate to 5 percent of useful beam 38
  21. Distance protection 38
  22. Primary protective barrier requirements 39
  23. Other dangers 42
  24. References 43

MEDICAL X-RAY PROTECTION UP TO TWO-MILLION VOLTS

I. General

1. Definitions

The following definitions are used in this Handbook. As they are few in number, they have not been arranged alphabetically, but rather in textbook form. They are not meant to be a glossary of radiation terms.

1.1. **Shall.** Is necessary to meet currently accepted standards of protection.

1.2. **Should, is recommended.** Indicates advisory requirements that are to be applied when possible.

1.3. **Roentgen (r).** The international unit of quantity for both X-rays and gamma rays adopted by the Fifth International Congress of Radiology at Chicago in 1937. It was defined by the International Committee for Radiological Units in the following words:

> "The International Unit of quantity or dose of X-rays or gamma rays shall be called the 'roentgen' and shall be designated by the symbol '*r*'. The roentgen shall be the quantity of X-or gamma-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 esu of quantity of electricity of either sign."

1.4. **Milliroentgen (mr).** A submultiple of the roentgen equal to one one-thousandth (1/1000) of a roentgen.

1.5 **Dose.** The total quantity of radiation in roentgens at a given point, measured in air. The expression "measured in air" has a definite meaning in radiology, namely, that the measurement is made at a given point in the radiation field without the presence of the human body.

1.6. **Dosage rate.** Dose per unit time.

1.7. **Permissible dosage rate.** The maximum total dose to which any part of the body of a person shall be permitted to be exposed continuously or intermittently in a given time.

It shall be 0.300 r per week. On the basis of 48 hours per week of uniform exposure, the permissible dosage rates are:

0.00625 r per hour (6.25 mr per hour).

1.04×10^{-4} r per minute (0.104 mr per minute).

1.74×10^{-6} r per second (0.00174 mr per second).

1.8. **X-ray apparatus.** Any source of X-rays, and its high-voltage supply, coming within the scope of this Handbook.

1.9. **Kilovolt (kv).** A unit of electrical potential equal to 1,000 volts.

1.10. **Kilovolts peak (kvp).** The crest value of the potential wave in kilovolts. When only one-half of the wave is used, the crest value is to be measured on this half of the wave.

1.11. **Radiation.** Energy propagated through space.

1.12. **Radiation field.** Region in which energy is being propagated.

1.13. **Radiation hazard.** Hazard that exists in any region to which a person has access while X-ray apparatus is in operation and the dosage rate is greater than the permissible dosage rate.

1.14. **Radiation survey.** A critical examination of the radiation near an installation by or under the supervision of a qualified expert.

1.15. **Primary radiation.** Radiation coming directly from the target of the X-ray tube. Except for the useful beam (1.16), the bulk of this radiation is absorbed in the tube housing (1.26).

1.16. **Useful beam.** That part of the primary radiation which passes through the aperture, cone, or other collimator.

1.17. **Direct radiation.** All radiation coming from within the X-ray tube and tube housing, except the useful beam.

1.18. **Secondary radiation.** Radiation emitted by any matter irradiated with X-rays.

1.19. **Scattered radiation.** Radiation which, during passage through a substance, has been deviated in direction. It may also have been modified by an increase in wavelength. It is one form of secondary radiation.

1.20. **Stray radiation.** Radiation not serving any useful purpose. It includes direct radiation and secondary radiation from irradiated objects.

1.21. **Lead equivalent.** The thickness of lead affording the same protection, under specified conditions, as the material in question.

1.22. **Aluminum equivalent.** The thickness of aluminum that will afford the same protection under specified conditions as the material in question.

1.23. **Protective barriers.** Barriers of X-ray-absorbing material, such as lead, concrete, or plaster, that are used to reduce radiation hazards.

1.24. **Primary protective barriers.** Barriers that reduce the useful beam to the permissible dosage rate.

1.25. **Secondary protective barriers.** Barriers that reduce the stray radiation to the permissible dosage rate.

1.26. **Tube housing.** An X-ray-tube enclosure that confines the major part of the radiation emerging from the enclosure to the useful beam.

1.27. **Fully protective tube housing.** Tube housing in which the direct radiation is reduced to at most 6.25 mr per hour at contact with the tube housing when the tube is continuously operated at its maximum rated curent for the maximum rated voltage.

1.28. **Therapeutic-type protective tube housing.** Tube housing in which the direct radiation is reduced to at most 1 r per hour at a distance of 1 meter from the tube target when the tube is operating continuously at its maximum rated current for the maximum rated voltage.

1.29. **Diagnostic-type protective tube housing.** Tube housings in which the direct radiation is reduced to at most 0.10 r per hour at a distance of 1 meter from the tube target when the tube is operating continuously at its maximum rated current for the maximum rated voltage.

1.30. **Qualified expert.** A person having the knowledge and training needed to measure radiations and to advise regarding radiation hazards. The physician or dentist employing him shall be responsible for seeing that he has the necessary training and education. Certification by competent authority or by a board set up for the purpose is desirable. Registered physicists certified by the American Board of Radiology are qualified experts.

1.31. **Personnel monitoring.** The systematic periodic check of the radiation dose each person receives during his working hours.

1.32. **Lead protective gloves.** Gloves made of materials containing lead or lead compounds for the purpose of reducing radiation hazards.

1.33. **Lead protective aprons.** Aprons made of materials containing metallic lead or lead compounds for the purpose of reducing radiation hazards.

1.34. **Half-value layer.** The thickness of absorbing material necessary to reduce the dosage rate of an X-ray beam to one-half its original value. One half-value layer would thus reduce the dosage rate to one-half; two half-value layers to one-fourth; three half-value layers to one-eighth, etc. The half-value layer depends not only upon the amount and waveform of the potential but also upon the amount and kind of absorbers through which the radiation has already passed. For use in this Handbook the half-value layer shall be the half-value layer in the region of the dosage rate considered.

1.35. **Occupied space.** Space which may be occupied by personnel during time that X-ray machines are operating.

2. Survey and Inspection

2.1. Plans for a new X-ray installation requiring structural shielding should be discussed with a qualified expert (1.30).

2.2 The possibilities of multiple exposure from several different X-ray tubes shall not be overlooked.

2.3. Final plans with the thickness and specifications for all protective barriers plainly marked, as well as the position of all pipes, windows, louvers, and doors with their baffles indicated, insofar as they pertain to the protection requirements, should have the approval of the expert (1.30).

2.4. Method of radiation survey (1.14).

a. A radiation survey should be made by a qualified expert (1.30) of all new installations requiring structural shielding and after every change in such existing installations. "Change in X-ray installations" shall be construed to mean a change by which the X-ray output has been increased or the protection of the barrier altered. For example, on an installation where the maximum output is governed by the tube limitation, a tube change shall mean a "change in the X-ray installation" only if the new tube will allow a higher X-ray output.

b. The installation as made should be compared with the plans and specifications previously approved.

c. If the safety of the installation depends upon the mechanical restrictions in the orientation of the X-ray beam and limitations in the X-ray output of the tube (voltage, current, time, permanent filter, and maximum aperture), then an inspection shall be made to see that these restrictions are actually imposed.

d. All interlocks and warning signs shall be inspected to ensure that they are operating properly.

e. A preliminary survey shall be made in the vicinity of the X-ray installation to determine where radiation hazards may exist and their probable sources. All positions which are, or could be habitually occupied during the time X-rays are on, shall be included in this preliminary survey. Such apparently hazardous positions shall be considered in this paragraph to be those where one-fifth or more of the permissible dosage rate is obtained. This factor will allow for calibration error of the quality-dependent instruments suggested for this preliminary survey. Geiger counters or ionization chambers may be used for this survey.

f. An accurate determination shall be made of the X-ray dosage rate for the tube operating at its maximum continuous X-ray output at all apparently hazardous points noted under 2.4e. An ionization chamber or other instrument with similar low variation in sensitivity with quality and direction shall be used for these observations. This instrument shall be calibrated for the quality at which it is to be used. Geiger counters and photographic films in their present state of development shall not be used for this determination.

g. Normal methods of operation of the X-ray equipment should be observed to see if proper precautions are being taken against radiation hazard.

h. A study shall be made of the personnel monitoring (1.31) technique if employed.

2.5 Report of radiation survey (1.14).

a. The results of a survey shall be submitted by the expert in a formal written report to the agency requesting the survey.

b. X-ray dosage rates at critical points shall be indicated in milliroentgens per hour on a scale drawing of the installation. If, at any of these positions, the permissible dose would be exceeded in a 48-hour week, the time that personnel may safely remain at this position shall also be indicated. These positions may be identified by numbers or letters on the scale drawing. A table could then give the dosage rates and times for each of these positions.

c. The position of personnel habitually located in regions of possible radiation hazard (1.13) shall be indicated.

d. The report shall include recommendations as to corrections in the operational technique, barrier thickness, or mechanical restriction of the beam that will eliminate radiation hazards (1.13) in occupied positions.

e. If radiation hazards (1.13) are found to exist, the expert should indicate whether a further survey is necessary after the fault has been remedied.

f. Recommendations shall include changes in the personnel monitoring (1.31) technique if required.

g. Copies of each report shall be kept on file by the expert (1.30) and by the physician or dentist in charge of the X-ray installation.

2.6. Periodic inspections.

a. At least every 6 months all protective devices that may become defective due to use or abuse, such as lead protective aprons or gloves, shall be inspected for radiation leakage. A qualified expert is not required for this inspection. Approximate determinations of radiation leakage by fluoroscopic examination, radiographs, Geiger counters, or ionization chambers are deemed sufficient.

b. This inspection shall include tests of the functioning of all interlocks.

c. Records of dates, findings, defects, and recommendations for remedial action for each such inspection shall be kept on file by the physician or dentist in charge of the X-ray installation.

2.7. Whenever electrical or radiation hazards (1.13) are found to exist they shall be promptly eliminated.

3. Working Conditions

3.1. The working conditions of the personnel in an X-ray department shall be the responsibility of the physician or dentist in charge.

3.2. The physician or dentist in charge shall be responsible for the instruction of new personnel in safe working practices for dealing with X-rays, and in the nature of injuries resulting from overexposure thereto. He should promulgate special safety rules for his department. These safety rules shall include any restrictions in the operating technique indicated as necessary by the survey report.

3.3. Every new employee (and every old one who has not read them) shall be required to read the sections of this Handbook pertaining to his work and the special safety rules. He shall then sign a statement that he has read them and understands their contents. This statement shall be filed.

3.4. Unnecessary or unauthorized exposure and the careless or intentional omission of protective devices shall be forbidden.

3.5. Personnel monitoring (1.31).

a. It is recommended that radiation monitoring be carried out in all cases where the safety of the workers depends upon the use of a proper operating procedure rather than adequate protective barriers as, for example, in the case of mobile, portable, or dental radiography, fluoroscopy, grenz ray, or contact therapy.

b. The physician or dentist in charge or a designated subordinate shall be responsible for the monitoring, if any, and safety of the group. He shall hand the monitoring device to each person to wear and collect it regularly for measurement. He shall keep accurate and permanent records of all his findings.

c. Photographic film may be used for monitoring. A securely fastened metallic marker, such as a lead marker or echelon, should be used to cast a shadow. These films are to be worn for a 1- to 4-week period,[1] on the portion of the worker's body likely to receive the most radiation. More than one film may be required.

d. On the advice of a qualified expert (1.30) monitoring may be obtained by having each employee carry appropriate ionization chambers.

e. Any significant darkening[2] of the film or discharge of the ionization chamber shall require an immediate investigation.

3.6. Health.

a. The physician or dentist in charge shall be responsible for the protection of personnel against radiation and electrical injuries and for the execution of the following regulations for all employees.

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[1] The length of this period will depend upon the sensitivity of the film used.

[2] The significance of this darkening shall be determined by comparison with film of the same type exposed to known quantities of radiation under the same X-ray quality conditions and processed in the same manner.

b. Preemployment examination. This shall entail an occupational history, a description of any unusual radiation exposure resulting from previous occupations, diagnostic radiographic examinations, or any radiation therapy received (including infancy and childhood), a detailed family history (for heritable disease), a complete physical examination, including a routine urine analysis, a chest plate, and a blood count. In the case of a married individual without children, a record of whether or not the absence of children is due to prophylactic measures is desirable.

c. The blood count shall include the red-cell count, hemoglobin, white-cell count, differential count, and a note as to the abundance of platelets in the blood smear.[3]

(1) The initial blood count shall be performed on two successive days at a stated hour. It is suggested that blood counts be performed at 3 p. m. If the first two counts show significant differences, a third shall be performed. These shall serve as a basis for future comparisons. Persons having a total white count of less than 4,000 shall not be accepted for employment.

(2) Blood counts should be repeated periodically. For departments that monitor their operations and personnel carefully by pocket chambers or film badges this interval should be not longer than 6 months; and for those installations where personnel monitoring is not practiced, the interval should be not more than 3 months. Blood count shall be performed whenever possibility of overexposure is suspected.

(3) Emphasis shall be placed upon trends in serial blood counts rather than one blood examination. A reduction of the white-cell count by 2,000 may indicate radiation injury, and should be investigated. However, in the majority of instances, this change represents a normal variation.

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[3] Changes in the blood count are usually the first biological indication conveniently obtainable of extensive overexposure to radiation. The occurrence of a change calls for an investigation to determine its cause: it is frequently a normal variation and reversible. There are no blood changes which dependably indicate incipient damage to personnel from radiation exposure, i. e., before real damage has occurred.

Investigators have found minor changes in the blood cells that might be significant of incipient radiation injury. These are tendency to anemia in females, propensity to polycethemia, tendency to leukopenia, less marked tendency to leukocytosis (shift to the left), hypersegmentation, granulocytopenia, and pothological lymphocytes. The evaluation of these features is a matter of clinical judgment.

(4) The physician in charge shall review all reports and take action when significant alterations are found. When any worker exhibits changes in the blood attributable to radiation overexposure, he shall be removed from his job and be placed under the care of a physician. An immediate survey shall be made to determine the source or cause of his overexposure.

d. A complete yearly physical examination and interval medical history is considered advisable for each worker who is routinely exposed to radiation.

e. All reports of physical examination and blood counts shall become a permanent record.

4. Structural Details of Protective Barriers (1.23)

4.1. The barriers shall be at least as absorbing as required under chapter II.

4.2. Lead barriers shall be mounted in such a manner that they will not creep because of their own weight. They shall be protected against mechanical damage. It is recommended that lead barriers of 1/32-inch thickness or less be constructed of some structural material, such as wood or metal panels, with a rigidly fastened lead coating.

4.3. Movable barriers should not be depended upon for total protection above 100 kilovolts.

4.4. Surfaces of lead sheets at joints shall be in contact with a lap of at least 1/2 inch or the thickness of the sheet, whichever is the greater.

4.5. Welded or burned lead seams are permissible, provided the lead equivalent of the seams shall be at least as large as that required under Chapter II.

4.6. Joints between different kinds of protective materials shall be so designed that the overlap is at least equal to the thickness of the thicker one.

4.7. Joints at floor and ceiling shall have sufficient protection so that scattering through the floor and ceiling is no larger than the transmission through the wall. The sum of scattered and transmitted radiation shall be less than the permissible dosage rate (1.7) for occupied space (1.35). (See fig. 1 for example that fulfills this requirement.)

4.8. Nails, bolts, or other fasteners through a lead sheet shall be covered by lead of thickness equal to that of the sheet. Overlap requirements are covered by section 4.4.

4.9. Windows and doors shall have the same lead equivalent (1.21) as that required of the surrounding wall. Over-

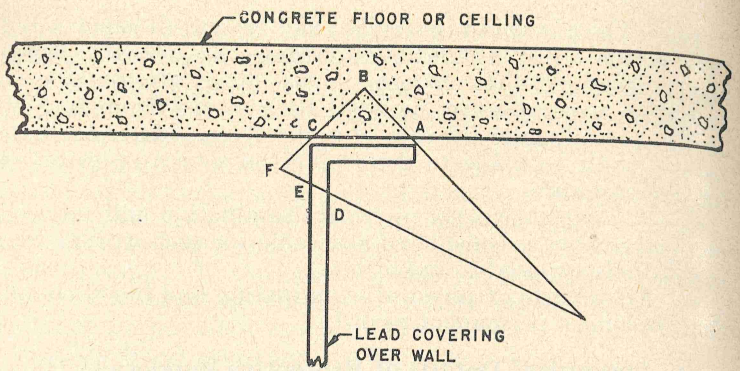

FIGURE 1. *Example of wall joint (for section 4.7)*

The sum of radiations through all paths ABCF and DEF to the point F shall not be more than the permissible dosage rate if F is to be occupied space. The framework supporting the lead wall is here considered to be of relatively X-ray-transparent material.

lapping requirements are governed by 4.6. A door baffle may be required above 125 kilovolts if the aperture can be struck by the primary beam. (See fig. 2 for example that fulfills the baffle requirement.)

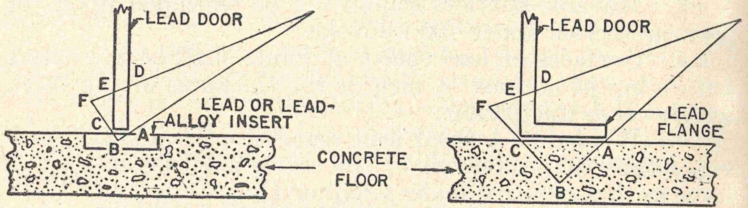

FIGURE 2. *Example of door baffle (for section 4.9)*

The sum of radiations through all paths ABCF and DEF to the point F shall not be more than the permissible dosage rate if F is to be occupied space. The supporting structure for the lead door is here considered to be a framework of relatively X-ray-transparent material.

4.10. Holes in the barrier for pipes, conduits, and louvers shall be provided with baffles so that radiation transmitted through them is not more than that transmitted by the surrounding barrier. Such holes should preferably not be struck by the primary beam.

5. Plans for an X-ray Installation

5.1. The X-ray installation should be placed as far as practicable from other occupied space. In special cases this factor may be sufficient to reduce the barrier-thickness requirements to zero. Such distances are indicated in table 4, page 38. These minimum safe distances shall be considered when omitting protection on outside walls and windows.

5.2. Considerable saving in wall-barrier requirements may be obtained by placing a large portion of the protection in the tube housing. It is recommended, therefore, that a protective tube housing (1.28, 1.29) be used. For hand-held tubes a fully protective tube housing (1.27) shall be used.

5.3. Mechanical restrictions for angulation of the tube will reduce the amount of protection required.

5.4. The number and size of the openings into the radiation room should be reduced to a minimum. Such requirements should be relaxed only when the walls face unoccupied space for at least the distance given in table 4, page 38.

5.5. The possibilities of multiple scattering from several different X-ray tubes or by several paths from a single X-ray tube into an occupied space should be investigated.

5.6 Protection for the useful beam (1.16) shall be computed without a patient in the beam.

5.7. The observation window should be placed so that the useful beam cannot be directed at it.

5.8. All protection shall be computed for maximum kilovoltage at the maximum continuous milliamperage rating for the shortest distance from target to occupied space and for an 48-hour week, unless otherwise noted in this Handbook.

II. Rules for Specific Applications

6. Fluoroscopic X-ray Installations for Potentials up to 100-Kilovolts Peak[4]

See section 9 for special requirements for mobile units

6.1. Equipment for fluoroscopy.

a. A diagnostic-type protective tube housing (1.29) shall be used.

b. The tube protective enclosure shall be provided with an adjustable diaphragm which, when open to its fullest extent, leaves a margin of at least 1/4 inch of unilluminated fluorescent screen with the screen at its greatest distance from the tube for any angulation of the table.

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[4] See notes following each protection requirement for information on higher potential applications.

c. Diaphragms or cones used for collimating the useful beam shall provide the same degree of protection as the tube housing. Because of the orientation of the cone wall relative to the X-ray beam, the cone will be considerably thinner than is required for the tube housing (1.26).

d. Tube diaphragms and screen should be mounted on a common support, so that they will always move together.

e. A permanent total filter equivalent of at least 2 millimeters of aluminum shall be provided. This filter equivalent shall be determined at the maximum kilovoltage of the X-ray machine.

f. The cone shall extend from the tube housing to as near the panel as possible.

g. The target to table panel distance shall not be less than 12 inches.

h. A "high-low" milliamperage change-over switch may be provided for the purpose indicated in 6.3c.

i. It is recommended that for prolonged fluoroscopic work a cumulative timing device be used, which will either indicate elapsed time or turn off the apparatus when the total exposure exceeds a certain previously determined limit given in one or in a series of exposures.

j. The fluoroscopic screen shall be covered with a transparent protective window having a lead equivalent of at least 1.5 millimeters for 100-kilovolts peak.[5]

k. The dosage rate measured at the panel shall be less than 20 r per minute at the maximum kilovoltage and 5 milliamperes. It is recommended that this be assured for each new installation.

6.2. Structural shielding for fluoroscopic installations.

If the point of occupied space nearest to the tube is 2 meters from the tube the protective barrier shall have a lead equivalent [6] of at least 0.5 millimeter for 100-kilovolts peak. Barrier requirements at other distances and kilovoltages shall be determined from the curve of figure 3, page 32, according to the rules outlined in section 19.1 for a tube current of 5 milliamperes.

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[5] For equipment capable of operating at potentials of from 100- to 150-kilovolts peak, an additional lead equivalent of 0.01 millimeter per kilovolt over 100-kilovolts peak shall be required.

[6] Concrete walls 2 inches thick or 0.11-inch-thick steel sheets are adequate for this protection.

6.3. Operation of fluoroscopic apparatus.

a. The fluoroscopic equipment shall be operated only by a member of the department of radiology or by a person properly trained and authorized by the radiologist in charge to conduct fluoroscopic examinations.

b. The fluoroscopist should have completely dark-adapted eyes before starting to work.

c. Fluoroscopic work shall be performed in the minimum time possible by using the lowest X-ray intensity and smallest aperture consistent with clinical requirements. If a high-low switch is available, as suggested in 6.1h, then the low intensity shall be used to locate the area of interest and the high intensity only to momentarily explore the area of interest.

d. Lead protective aprons (1.33) shall be worn by the physician, technician, and all other personnel within the fluoroscopic room who are frequently or habitually exposed to radiation hazard. The lead equivalent of the apron shall be at least 0.4 millimeter measured at 80 kilovolts.

e. Lead protective gloves (1.32) should be worn during every examination. They shall cover the whole hand—outer surface, palm, fingers, and wrist—with a lead equivalent of at least 0.5 millimeter measured at 80 kilovolts.

f. The hand of the fluoroscopist either with or without gloves shall never be placed in the useful beam of radiation.

g. Only persons actually needed in the fluoroscopic room should be there during the X-ray exposure.

7. Radiographic Installations for Potentials up to 100-Kilovolts Peak[7]

(See section 8 for special requirements with dental units, section 9 for special requirements with mobile units, and section 10 for special requirements for fluorographic apparatus.)

7.1. Equipment for radiography.

a. A diagnostic-type protective tube housing (1.29) shall be used.

b. Diaphragms or cones used for collimating the useful beam shall provide the same degree of protection as the tube housing. Because of the orientation of the cone wall relative to the X-ray beam, the cone will be considerably thinner than is required for the tube housing.

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[7] See notes following each protection requirement for information on higher potential application.

c. A filter of at least 1 millimeter of aluminum should be added for radiographing thick parts of the body.

d. The aluminum equivalent of the table top shall not be more than 0.5 millimeter at 80 kilovolts when a Bucky is used under the table top.

e. It is recommended that a timer or radiation exposure meter be provided to terminate the exposure after a preset time or exposure.

f. Exposures shall be initiated only from the control. A "dead-man" type of exposure switch shall be used so that the operator cannot leave the control during exposure.

7.2. Structural shielding for radiography.

a. Radiographic room floors and walls for a height of 7 feet (assuming that the useful beam will not strike the wall above this distance) shall have a primary protective barrier (1.24). Five half-value layers may be deducted from the requirements of table 5, page 40, for 100-kilovolts peak[8] to obtain the thickness of this primary protective barrier. Table 4, page 38, for a target current of 0.25 milliampere gives distances required from the X-ray tube to occupied space for complete protection without regard to intervening walls.

b. Secondary protective barriers are not required unless the space above the radiation room is occupied and separated by frame construction.

c. Control apparatus for the radiographic equipment shall be located in an adjacent room or in a booth within the same room. Protection equivalent to 1.5 millimeters[9] of lead shall be required between the control and radiation rooms. The control booth shall be provided with a lead-lined door or be so constructed that the radiation has to be scattered at least twice before entering the booth. If the control apparatus is in a booth within the radiographic room, the floor joint shall meet the specifications of 4.7.

d. The control room or booth shall be provided with a suitable window of 1.5-millimeter[10] lead equivalent (1.21) at 100-kilovolts peak.

e. Special attention shall be given to protection of undeveloped X-ray film, for these may be damaged by total exposures of less than 1 milliroentgen. It is suggested that only a small supply for current needs be stored in or near the X-ray rooms. A lead-lined box may be used for such storage. The main supply should be as far removed from the X-ray room as practicable. Such storage may also require lead protection.

7.3. Operation of radiographic apparatus.

a. The radiographic installation should be so arranged that the useful beam is directed away from occupied regions where possible.

b. A competent operator shall be at the control during any radiographic exposure.

c. When it is necessary to hold the patient during the exposure no person shall be regularly so employed nor shall anyone from the department of radiology be permitted to perform such service. The person holding the patient should wear lead protective gloves and a lead protective apron. No part of this person's body shall be in the useful beam.

d. No persons other than the patient and those needed to hold the patient shall be in the radiographic room during exposure.

e. Radiographic work shall be performed with the smallest field consistent with clinical requirements.

f. Protection of the patient from serious overdosage is sometimes overlooked in the desire to obtain diagnostic objectives. Table 1 is inserted as a guide to indicate the dosage rates to be expected in the radiographic voltage range.

TABLE 1. *Approximate air-dosage rates (roentgens per 100 milliampere seconds) for pulsating potential with a 1.0-millimeter aluminum filter added*

Target-skin distance		Kilovolts						
		50	60	70	80	90	100	125
cm	*in.*							
30	------	3.6	5.4	7.5	9.7	13	15	22
------	18	1.6	2.4	3.2	4.2	5.5	6.4	9.6
50	------	1.3	2.0	2.7	3.5	4.6	5.3	8.0
------	24	0.9	1.4	1.9	2.3	3.1	3.6	5.4
------	36	.4	0.6	0.8	1.0	1.4	1.6	2.4
100	------	.3	.5	.7	0.9	1.1	1.3	2.0
------	72	.1	.15	.2	.25	0.35	0.4	0.6

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[8] For equipment capable of operating at potentials of from 100- to 150-kilovolts peak, an additional lead equivalent of 0.01 millimeter per kilovolt over 100-kilovolts peak shall be required.

[9] See footnote 8.

[10] See footnote 8.

8. Dental Roentgen Installations Operated at Potentials up to 70-Kilovolts Peak

8.1. Equipment for dental installations.

a. A diagnostic-type protective tube housing (1.29) shall be used.

b. Diaphragms or cones used for collimating the useful beam shall provide the same degree of protection as the tube housing. Because of the orientation of the cone wall relative to the X-ray beam, the cone will be considerably thinner than is required for the tube housing (1.26).

c. Diaphragms should reduce the beam to as small a cross section as is consistent with radiographic requirements.

d. A timer shall be provided to terminate the exposure after a preset time.

e. The exposure control switch shall be of the type that must be manually held "ON" for operation.

8.2. Structural shielding for dental installations.

a. If the apparatus is to be used for less than 250 milliampere minutes (15,000 milliampere seconds) per week and if the other persons habitually in the region of the X-ray machine are at least 4 feet from the target and patient and out of the useful beam[11] for all exposures, no structural shielding shall be required.

b. When the apparatus is to be operated for more than 250 milliampere minutes per week or when more than one equipment is used in one room, structural shielding shall be required. A lead equivalent of 0.8 millimeter measured at 60-kilovolts—concrete walls 3½ inches thick or 0.17-inch-thick steel sheets are adequate for this protection—is required for all walls, floor, and ceiling between the target and occupied space. The operator shall stand behind a screen having a lead equivalent of at least 0.8 millimeter measured at 60 kilovolts. Such a screen is often hinged to the wall so that it can be folded out of the way when the equipment is not in use.

c. In case dental X-ray equipment is installed in adjacent rooms, protective barriers (1.23) as specified in 8.2b shall be provided.

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[11] A distance of approximately 60 feet without intervening walls would reduce this useful beam to the permissible weekly dose.

8.3. Operation of dental installations.

a. Under no condition shall the operator or any regular assistant hold a film in place when an X-ray is taken. In case of emergency a relative or other person not habitually exposed to X-rays may hold the film.

b. For routine operation, only the patient shall be in the useful beam.

c. The tube housing (1.26) shall not be hand held during exposure.

d. The operator's position shall comply with 8.2a or 8.2b, which ever is pertinent.

9. Special Requirements for Mobile Diagnostic Equipment Operating at Potentials up to 100-Kilovolts Peak

9.1 Equipment for mobile apparatus.

a. A diagnostic-type protective tube housing (1.29) shall be used.

b. All mobile equipment shall be provided with cones or metal frames so that the minimum target-skin distance is at least 12 inches.

c. A fixed total filter of at least 1.5 millimeters aluminum shall be provided.

9.2. Operation of mobile apparatus.

a. The technician should stand as far as possible from the tube and patient during exposure.

b. The operator shall not stand in the useful beam.

c. An operator, standing at least 6 feet from the tube and patient, should not make more than 15,000 milliampere seconds of exposure during any one week. This corresponds approximately to the weekly permissible dose. Rotation of operators or wearing of lead protective aprons is recommended for longer exposures.

10. Fluorographic Equipment Operating at Potentials up to 100-Kilovolts Peak[12]

10.1. Equipment for fluorography.

a. A diagnostic-type protective tube housing (1.29) shall be used.

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[12] The protection recommended below is based on an assumed 4,000 milliampere minutes of exposure per week. See notes following each protection requirement for information on higher potential application.

b. Diaphragms or cones for collimating the useful beam shall provide the same degree of protection as the tube housing.

c. A lead frame 1.5 millimeters thick[13] shall extend out on all sides of the screen to a distance of at least 1 inch beyond the useful beam, as defined by the cone or diaphragm.

10.2. Structural shielding for fluorography.

a. A primary protective barrier (1.24) whose lead equivalent is at least 1.5 millimeters at 100-kilovolts peak,[14] shall be provided either around the light hood between the screen and the camera and around the camera or behind the camera.

b. If occupied space is 6 feet from the target, a secondary protective barrier (1.25) whose lead equivalent is 0.5 millimeter at 100-kilovolts peak shall be required in that direction. If occupied space is more than 35 feet from the target in a certain direction, no secondary protective barriers are required in that direction. Barrier requirements at other kilovoltages shall be determined from the curve of figure 3, page 32, according to the rules outlined in section 19.1 for a tube current of 1.4 milliamperes.

10.3. Operation of fluorographic apparatus.

a. The controls shall be operable only from behind the protective barrier.

b. If movable protective barriers are used, personnel monitoring shall be required.

11. Therapeutic X-Ray Installations Operated at Potentials up to 250 Kilovolts

11.1. Equipment for therapy apparatus, up to 250 kilovolts. (See section 11.4 for special requirements.)

a. A therapeutic-type protective tube housing (1.28) shall be used.

b. Permanent diaphragms or cones used for collimating the useful beam shall have the same degree of protection as the tube housing. Adjustable, beam-defining diaphragms when used shall allow transmission of not more than 5 per cent of the useful beam dosage rate (1.6) outside of the useful beam (table 3, p. 38).

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[13] For equipment capable of operating at potentials of from 100- to 150-kilovolts peaks, an additional lead equivalent of 0.01 millimeter per kilovolt over 100-kilovolts peak shall be required.

[14] See footnote 13.

c. All filters shall have their thickness clearly marked on them. A filter-indicating system is recommended at the control showing the thickness and material of the filter in the useful beam. The filters shall be held firmly in place to prevent them from dropping out during treatments. The filter opening shall be so arranged that the scattered radiation from it gives a minimum contribution to the radiation hazard (1.13).

d. The X-ray tube shall be accurately centered in the tube housing and shall be rigidly mounted to prevent turning and sliding. The location of the focal spot should be indicated by suitable marking on the tube housing. If the inherent filtration of X-ray tube and tube housing for the useful beam is very low, such as in a beryllium window tube, then a special danger exists and extreme care should be exercised in its use.

e. All means of angulation and movement of the X-ray-tube head shall be provided with devices for preventing shifting during treatments.

f. Valve tubes may require shielding if they are not located in the treatment room.

g. The control shall be provided with a timer that automatically terminates the exposure after a preset time.

h. At potentials above 150 kilovolts an ionization chamber fixed in the useful beam is recommended to indicate any error due to incorrect filter, milliamperage, or kilovoltage. If low inherent filtration is not required in the 50- to 150-kilovolt region, an ionization chamber is also recommended in that range.

i. Lead rubber, lead foil, and other materials used for limiting the field should have a sufficient lead equivalent to reduce the dosage rate outside of the defining aperture to 5 percent or less of the dosage rate of the useful beam. See table 3, page 38, for the lead equivalent required for different radiation qualities.

11.2. Structural shielding for therapeutic X-ray installations operating up to 250 kilovolts. (See section 11.4 for special requirements.)

a. The barriers required to protect against the useful beam (1.16) and the scattered radiation (1.19) should be incorporated in the building construction with the control located outside of the treatment room. Movable lead screens are not recommended and shall not be depended upon above

100 kilovolts. Where employed, these screens require surveys, as covered by section 2.

b. The cost of structural shielding may be reduced considerably by locating the treatment rooms as remotely as possible from occupied regions, taking advantage of the reduction due to the "inverse-square law". This is particularly true for the higher voltages. Corner rooms are especially suited as the outside walls and windows do not require any protection if they are sufficiently distant from other occupied buildings and areas. See table 4, page 38, for the minimum distance required. Where most roentgen-ray treatments are given with the beam pointed toward the floor, special consideration shall be given to the protection of persons habitually in the rooms directly below the treatment room.

c. The control shall be located outside the treatment room for voltages above 100 kilovolts.

d. Where it is planned to provide unlimited irradiation for all possible orientations of the useful beam and for all possible locations of the X-ray tube target, the protection requirements shall be as follows: (*a*) All areas of the walls, floor, and ceiling of treatment rooms that may possibly be exposed to the useful beam, plus a border of at least 1 foot, shall be provided with primary protective barriers (1.24). Table 5, page 40, gives the thicknesses required for such protection. The shortest possible target distance with maximum kilovoltage and continuous milliamperage shall be assumed. (*b*) All other areas of the treatment room shall be provided with secondary protective barriers (1.25). A method for computing the thicknesses of such barriers is given in section 19.1b.

e. If the beam is directed toward the floor for more than 90 percent of the treatment time, the barrier thickness of the ceiling and the walls above 7 feet may be three half-value layers less than the primary protective barrier requirements. Such an installation shall require personnel monitoring, as outlined under section 3.5.

11.3. Operating methods for therapeutic installations operating up to 250 kilovolts. (See section 11.4 for special requirements.)

a. The X-ray installation shall be operated in compliance with any further limitations indicated by the radiation-protection survey.

b. Only the patient shall be in the treatment room during exposure, except when it is necessary to hold the patient, as in the case of small children. No members of the radiologic staff nor other persons normally near X-ray equipment or radioactive materials shall hold the patients during irradiation. The person holding the patient shall not be in the useful beam and shall be protected as much as practicable from scattered radiation.

c. The patient and X-ray control shall be under observation during exposure. Provision for oral communication with the patient from the control is desirable.

d. The useful beam (1.16) should be directed toward unoccupied regions if consistent with therapeutic requirements.

11.4 Special requirements for X-ray therapy equipment operating at potentials up to 50 kilovolts.

a. Structural shielding is generally not required for X-ray equipment operating at voltages of 50 kilovolts and less. However, as the operator is usually in the treatment room during irradiation, special care shall be taken to avoid exposure to the useful beam. Due to the short target distance and low inherent filtration the dosage rate at the tube aperture may be extremely high. An installation shall comply with the general requirements, except that radiation monitoring (11.1h) and structural shielding (11.2) are not required.

b. The term "grenz ray" is used to describe very soft roentgen rays produced at voltages below 15 kilovolts. Because of the low penetration of these rays it is not necessary to shield the operator or other persons in the treatment room unless they are exposed to the useful beam at a target distance of less than 3 meters. However, it should be emphasized that grenz rays are roentgen rays and that they may cause the same type of injurious effects as harder roentgen rays, although limited to superficial layers of tissue.

c. The term "contact therapy" is used to describe short distance irradiation of accessible lesions. The potential is usually 40 to 50 kilovolts. Because of the short target-contact distance, about 2 centimeters, the dosage rate at contact is very high (about 10,000 roentgens per minute with existing equipment), necessitating rigid precautions to prevent accidental exposures to the useful beam. If the tube is hand-held during irradiation, it shall have a fully protective housing (1.27), and it shall be provided with adequate shielding against scattered radiation. Unless the tube housing is furnished with a radiation shield or the total exposure is limited to 6 minutes per week, the operator shall wear lead protective gloves (0.5 millimeter lead equivalent) and apron (minimum of 0.4-millimeter lead equivalent). A cap (0.5-millimeter lead equivalent) should cover the aperture window of the tube housing when not being used for treatments. The automatic timer shall be graduated at least as fine as 1 second.

d. Special precautions shall be required in the therapeutic application of X-ray tubes constructed with beryllium or other low-filtration windows for both grenz ray and higher kilovoltage therapy. As a dosage rate of more than 1 million roentgens per minute is possible at the aperture, adequate shielding shall be required against the useful beam, and special safeguards are essential to avoid accidental exposures.

12. Therapeutic X-Ray Installations Energized by Potentials of 251 to 2,000 Kilovolts

12.1. Equipment for therapeutic installations.

a. A therapeutic-type protective tube housing (1.28) shall be used.

b. Permanent diaphragms or cones used for collimating the useful beam shall provide the same degree of protection as the tube housing. Adjustable, beam-defining diaphragms shall prevent transmission of more than 5 percent of the useful beam dosage rate outside of the useful beam (table 3, p. 38).

c. All linear and angular adjustments of the X-ray tube shall be provided with means to prevent shifting of the tube head during treatment.

d. An ionization chamber fixed in the useful beam should be provided to indicate any error due to incorrect filter, milliamperage, or kilovoltage.

e. The control shall be provided with a timer that terminates the exposure after a preset time.

f. All access doors to the treatment room and other hazardous areas shall be provided with electrical interlocks and warning signs.

12.2. Structural shielding for therapeutic installations energized by potentials of 251 to 2,000 kilovolts.

a. The general rules outlined under sections 4 and 5 shall be followed for structural shielding.

b. Primary protective barriers[15] (1.24) shall be provided for any position that the beam may strike with the largest possible diaphragm opening while the tube remains within the mechanical restriction of the tube mounting. A lead barrier shall extend for at least 6 inches beyond the edges of the useful beam for any possible orientation of the beam (for concrete, 12 inches). The actual protection requirements may be obtained from the curves of figures 4, 5, and 6 (p. 33–35) or from tables 6, 7, 8, and 9 (p. 40–42). If the beam is directed toward the floor for more than 90 percent of the treatment time, the primary protective-barrier requirements of the ceiling and the walls above 7 feet may be reduced by three half-value layers. Such an installation, however, shall require personnel monitoring, as outlined under section 3.5.

c. Barrier requirements for protection against direct radiation may be obtained from figure 4, 5, or 6 (p. 33–35). As attenuation data are not yet available for this computation, it is necessary to use the same attenuation curves as for the useful beam. The "straight" part of the attenuation curve should be used for this determination.

d. X-rays scattered from the patient or from barriers at 90 degrees to the useful beam should be assumed to have a dosage rate measured at 1 meter from the scatterer of 0.1 percent of the useful beam (1.16) measured at the scatterer. The scattered-beam absorption curves should be assumed[16] to be the same as those of the useful beam up to 500 kilovolts and equal to 500 kilovolts for all higher potentials.

e. Secondary protection (1.25) should be calculated for the conditions of 12.2c and 12.2d. If the barrier thickness required for the direct radiation and for the scattered radiation are nearly equal, then an extra half-value layer should be added to the larger thickness to obtain the structural thickness required. If one of the above computed thicknesses is at least three half-value layers greater than the other, then it alone will govern thickness requirements of the secondary protective barriers (1.25).

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[15] It should be noted that the requirements here will depend to some extent upon whether the useful beam is from a reflection or a transmission target and upon the waveform of the voltage source. Data are available now only on reflection targets at 400-kilovolts peak and transmission targets at 500 and 1,000 kilovolts and 2,000-kilovolts peak.

[16] This is only an approximation, which has been found to be quite safe. Actually, the absorption curves and the intensities of the scattered radiations are somewhat different from those used for this approximate rule.

f. A maze may be found economical in the million-volt range for reducing the thickness requirements of the access door to the treatment room. The access door shall be on the other end of the maze from the treatment room.

g. The control shall be located outside the treatment room.

h. The observation window shall have the same lead equivalent (1.21) as required for the surrounding wall.

12.3. Operating methods for therapeutic installations energized by potentials of 251 to 2,000 kilovolts.

a. The X-ray installation shall be operated in compliance with any limitation indicated by the radiation protective survey.

b. The patient and X-ray control shall be under observation during exposure. Provision for oral communication with the patient from the control is desirable.

c. Personnel shall be limited by interlocks and signs to locations wherein the permissible dosage rate is not exceeded. Interlocks shall be provided for all movable gates, doors, panels, or windows that give access to space where a radiation hazard exists. Warning signs shall be used for infrequently occupied space where radiation hazards exist. An outside wall where the space outside the wall is seldom occupied would be an example requiring such signs. It is recommended that the following words be used:

X-rays! Do not loiter!

Lighting of such signs during X-ray exposure is considered advisable.

III. Electrical Protection

13. General

13.1. Installation of electrical components of X-ray apparatus shall comply with the applicable requirements of the latest approved edition of the National Electrical Code. The National Electrical Code is the standard of the National Board of Fire Underwriters and is approved by the American Standards Association.

13.2. X-ray apparatus shall not be installed or operated in dangerous locations, for example, anesthetic rooms in which inflammable or explosive gases or dusts may be present, unless the apparatus is of approved[17] explosion-proof type or is approved for the location by the authorities having jurisdiction.

a. Inflammable anesthetics shall include ether, ethylene, propylene, ethyl chloride, cyclopropane, and nitrous oxide when combined with any of these. Nitrous oxide alone or with oxygen is safe.

b. All open high-tension generating equipment shall be located in a well-ventilated room completely isolated from the anesthetic room and any connecting doors or windows shall be effectively airtight. (For instance, the doors should close against soft rubber or felt padding.)

c. A completely self-contained transformer and X-ray-tube unit in an effectively airtight enclosure, or an oil-insulated shockproof X-ray-tube head connected by shockproof cables to the transformer is recommended for use in an anesthetic room. Both the high-voltage and low-voltage terminals shall be vapor sealed. One possible form of vapor sealing employs a semisolid dielectric.

d. The control panel for the X-ray unit, electrically driven blowers for cooling the X-ray-tube enclosure, electrically driven high-tension switches, toggle switches, foot or hand switches, relays, contactors, and film-viewing illuminators shall not be located or operated in anesthetic rooms unless they are of an approved explosion-proof type.

13.3. Connection to power mains.

a. A supply of more than 600 volts between lines or to ground shall not be brought to the control panel or to any other control point of X-ray apparatus.

b. X-ray apparatus shall be provided with suitable wiring terminals for the connection of conductors of at least the size corresponding to the maximum continuous input rating of the apparatus and for grounding. Unless the terminals are located within the control cabinet or within other enclosures, they shall be protected with suitable grounded cover plates or guards.

c. All cords, cables, and external wiring employed for supply connections and for connections between components, shall be adequate for the purpose and be maintained in good condition. Provision shall be made to protect them from mechanical damage, and those that are likely to be exposed to transformer oil shall be oil-resistant.

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[17] In chapter III the word "approved" refers to approval for listing by Underwriters' Laboratories, Inc., or other testing laboratories approved by the authority having jurisdiction.

d. Transportable X-ray apparatus of any capacity may be connected to its power supply by suitable temporary connections and heavy-duty cable or cord. Mobile apparatus requiring a 115-volt line fused for 30 amperes or less may be connected to the line by means of a flexible cord and attachment plug adequate for the purpose and approved for the rating of the apparatus.

e. Stationary X-ray equipment shall be connected to the power mains by permanent wiring.

f. Each X-ray unit shall be provided with a means of disconnecting it from the supply power circuit.

(1) For mobile apparatus properly connected to a 115-volt 30-ampere line, the disconnecting means may be a suitable plug and receptacle, the voltage and wattage rating of which is clearly and permanently indicated.

(2) Mobile apparatus for connection to circuits in excess of 115 volts and 30 amperes may employ as the disconnecting means a plug and receptacle, providing it is one of local installation and approval, or specifically approved for the purpose.

(3) For all stationary equipment and for mobile apparatus of rating higher than that specified in 13.3f (1), the disconnecting means may be an approved enclosed switch or circuit-breaker. The switch or circuit-breaker shall be provided with a means of locking in the "OFF" position to prevent unauthorized use of the equipment and shall be enclosed in a grounded metal box. A double-pole switch should be used for direct and single-phase current and a triple-pole switch for three-phase current. In the use of a 220-volt, three-wire, single-phase system, the neutral shall be unfused.

(4) The disconnecting means shall not be a part of the apparatus but should be readily accessible to the operator, preferably within sight of the control panel.

(5) The disconnecting means shall control only the X-ray apparatus and shall be interposed between the X-ray apparatus and any supplying transformer, rotary-converter, or motor-generator set.

13.4. Overload protection.

a. An overload protective device in addition to the fuses shall be provided within X-ray apparatus of greater than 2.5-kilovolt-ampere rating, which shall open all ungrounded supply conductors to the low-voltage winding of the high-voltage transformer or generator, and which cannot be held closed under overload conditions. The device shall provide suitable positive indication of whether the contactor is open or closed.

b. The value of the tripping current should be adjustable, and if manually adjusted, the value should be clearly indicated on the circuit-breaker.

c. The tripping current shall be adjustable to not more than a maximum of 125 percent of rated load on the primary of the transformer, based on the maximum working voltage and current.

d. Equipment providing automatic selection of X-ray-tube current should in addition provide for automatic adjustment of the overload-relay tripping current.

13.5. Control switches.

a. The control panel shall contain a manually operable mainline switch that will de-energize the apparatus. This switch shall break both sides of the incoming single-phase line.

b. Hand or foot switches used to energize X-ray apparatus, but not an integral part of the control panel, which may be operated at a position removed from the control, and switches which are an integral part of the control but which are used to energize the apparatus in the absence of a timer, shall be so constructed that they must be held "ON" for operation and return automatically to the "OFF" position when pressure is removed.

c. No locking device to hold the hand or foot switch in the "ON" position shall be permitted. If the switch operates through a relay, the relay shall open upon release of the switch.

d. A device shall be provided on the control panel for deenergizing, when not in use, either a hand switch located at a distance from the control panel or a foot switch. The device may be a toggle switch or an operation selector switch.

e. When used with equipment not completely shockproof, a foot switch shall be provided with a rigid shield above the button, arranged so that the switch cannot be closed by accidentally stepping on it.

f. Means shall be provided for protection against failure of electrical controlling switches used in moving X-ray-tube heads and elevating tables. These means shall provide for stopping the motor and other devices that might crush the patient.

13.6. Electrical components.

a. All components of X-ray apparatus and their combination into an X-ray unit, together with the interconnecting wiring, shall be of approved types complying with such electrical codes as are applicable.

b. Switches, magnetic locks, and other electrical components comprising electrical interlocks intended to prevent access to high-voltage enclosures and the like shall be of approved types.

c. Accessory X-ray equipment such as motor-driven tilting tables, Bucky diaphragms, spot-film tunnels, light localizers, and other similar electrical accessories, together with their interconnecting wiring, should be of approved types.

14. Protection From High-Voltage Circuits

14.1. High-voltage generators, capacitors, X-ray tubes, and conductors, unless of fully enclosed shockproof type, shall be made inaccessible by means of insulating enclosures or of grounded metal barriers or enclosures.

a. Any door, gate, port, or panel permitting ready access to the interior of high-voltage enclosures shall be provided with reliable interlocks, which shall deenergize the primary circuit of the high-voltage transformer when they are opened.

b. A switch shall be provided within the enclosure, by which a person working within the enclosure can prevent the energizing of the high-tension transformer.

c. Enclosures and barriers for exposed high-voltage capacitors or the conductors to such capacitors shall have in addition to access interlocks, devices so arranged that both sides of the high-voltage circuit are automatically short-circuited and grounded when the door or cover to the enclosure is opened.

d. In the case of shockproof equipment containing high-voltage capacitors, where automatic-discharging devices are not provided, due care should be exercised upon exposing the high-voltage circuit in the process of servicing either at the tube terminals or at the transformer terminals. Permanent warning signs should be posted near to the point of access to such terminals, supplying directions for discharging the capacitors. The capacitance of shockproof cables should also be considered and means for discharging them provided when necessary.

14.2 Where more than one X-ray tube or other piece of apparatus is to be operated independently from the same high-voltage generator, each shall be provided with a high-voltage switch or equivalent disconnecting means. Such disconnecting means shall be so constructed, enclosed, or located that inadvertent contact with its live parts cannot occur.

14.3. A grounded metal grid or screen may serve as the protective barrier for exposed high-voltage circuits, if sufficiently rigid.

14.4. Protective barriers of insulating material, including the air space between the latter and any high-voltage part, shall provide the necessary insulation to withstand twice the maximum operating voltage to ground, and they shall in no case be placed nearer to any high-voltage part than the equivalent needle-point spark-gap distance, corresponding to the maximum operating voltage of the conductor to ground, as given in table 2.

TABLE 2. *Approximate needle-point spark-gap distance for peak voltages up to 300 kilovolts*

[760-millimeter atmospheric pressure and 20° C]

Kilovolts (peak)	Needle-point gap		Kilovolts (peak)	Needle-point gap	
	cm	*in.*		*cm*	*in.*
5	0.42	0.17	120	19.8	7.81
10	.85	.33	130	22.0	8.65
15	1.30	.51	140	24.1	9.48
20	1.75	.69	150	26.1	10.3
25	2.20	.87	160	28.1	11.1
30	2.69	1.06	170	30.1	11.9
35	3.20	1.26	180	32.0	12.6
40	3.81	1.50	190	33.9	13.3
45	4.49	1.77	200	35.7	14.0
50	5.20	2.05	210	37.6	14.8
60	6.81	2.68	220	39.5	15.5
70	8.81	3.47	230	41.4	16.3
80	11.1	4.36	240	43.3	17.0
90	13.3	5.23	250	45.2	17.8
100	15.5	6.10	300	54.7	21.6
110	17.7	6.96			

14.5. Permanent overhead nonshockproof high-voltage systems shall be of metal rods or tubes of sufficient diameter to provide rigidity and to prevent corona, and they shall be suspended by insulating supports capable of withstanding at least twice the weight of the part of the structure they support and in no case less than 50 pounds dead weight. Sharp edges or points in the high-voltage system should be avoided in order to minimize brush discharges.

a. The use of nonshockproof high-voltage cables to X-ray tubes on existing X-ray equipment is considered obsolete. The requirements for such installations are given in National Bureau of Standards Handbook 20.*

b. The use of shockproof tube enclosures providing for connection to the overhead high-voltage system or to the high-voltage transformer by means of shockproof cables or the use of shockproof self-contained tube and transformer units is recommended for new installations.

14.6. High-voltage parts, if any, of oil or water coolers, shall comply with all regulations pertaining to high-voltage apparatus.

14.7. All portable and mobile X-ray apparatus shall be of the fully enclosed shockproof type, with no exposed live parts.

14.8. All flexible high-voltage shockproof cables shall be provided with a metal sheath that is grounded.

15. Grounding

All exposed noncurrent-carrying metal parts of X-ray apparatus, including protective guards, barriers, enclosures, and shields, shall be permanently grounded in accordance with the applicable provisions of the latest edition of the National Electrical Code. Other metal objects in the vicinity of exposed high-voltage parts, which may become charged by induction, should also be grounded.

16. Warnings and Instructions

16.1. At entrances to and within rooms that contain exposed high-voltage apparatus or conductors there shall be prominent signs warning of the danger of high voltage. It is also recommended that automatic visual signals be provided that operate when high-voltage circuits are energized.

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*Although this Handbook is now out of print, it is believed that copies will be available for reference use in most of the lending libraries. If not readily available, write to the National Bureau of Standards.

16.2. A copy of the applicable safety rules and first-aid instructions for electrical shock and burns shall be posted conspicuously in the principal X-ray rooms, together with the names and addresses of those physicians and members of the organization who are to be called upon in emergencies.

16.3. A qualified employee shall be responsible for the instruction of X-ray workers in the use of safety rules, in the practice of first aid, and in fire-fighting procedure.

17. First-Aid and Fire-Extinguishing Devices

A supply of suitable first-aid and fire-extinguishing devices and equipment approved for use with electrical apparatus shall be provided in conspicuous places and be appropriately labeled.

18. Inspection and Maintenance

18.1. Before any X-ray generator or high-voltage part is touched or any electrical enclosure opened, care should be taken to make sure that the apparatus is disconnected from the power line and all capacitors discharged. It is recommended that before any servicing operation is begun, the disconnecting means be padlocked in the "OFF" position, or where a plug and receptacle is used, that the plug be removed by the person while servicing the equipment and be placed within his sight during the service period, if practicable.

18.2. When the work being done requires more than one person, distinct signals shall be exchanged before high voltage is applied.

18.3. Inspections should be made at least bimonthly of high-voltage systems for possible loose parts or faulty insulators; of high-voltage barriers and interlocks; and of grounding connections. A general inspection of electrical components should be made at least once a year.

IV. Appendix

19. Radiation Attenuation Curves

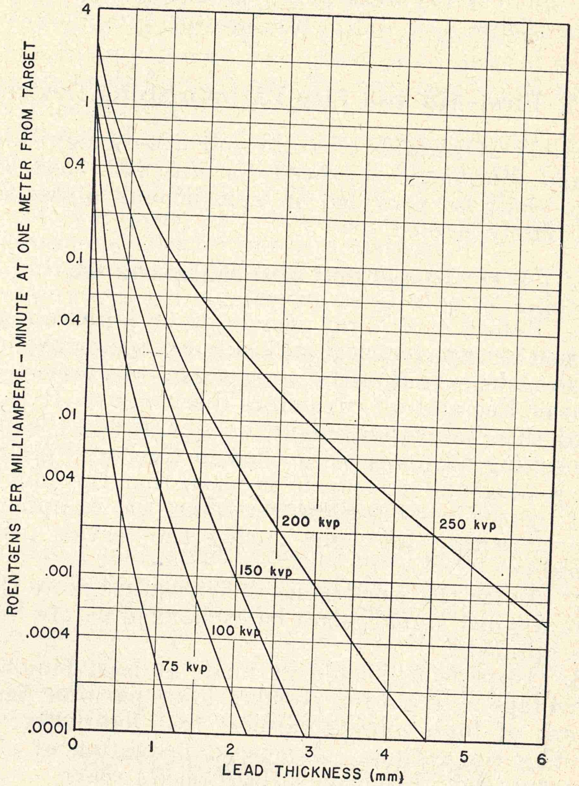

Figure 3. *Attenuation in lead of X-rays produced by potentials of 75- to 250-kilovolts peak.*

The curves were obtained with a half-wave generator and with a 90-degree angle between the electron beam and the axis of the X-ray beam. The filter was 3 millimeters of aluminum for the 150-, 200-, and 250-kilovolts peak curves and 0.5 millimeter of aluminum for the 75- and 100-kilovolts peak curves. Direct-current potentials require 10-percent-thicker barriers than for the pulsating potentials given above. (C. B. Braestrup, 1944).

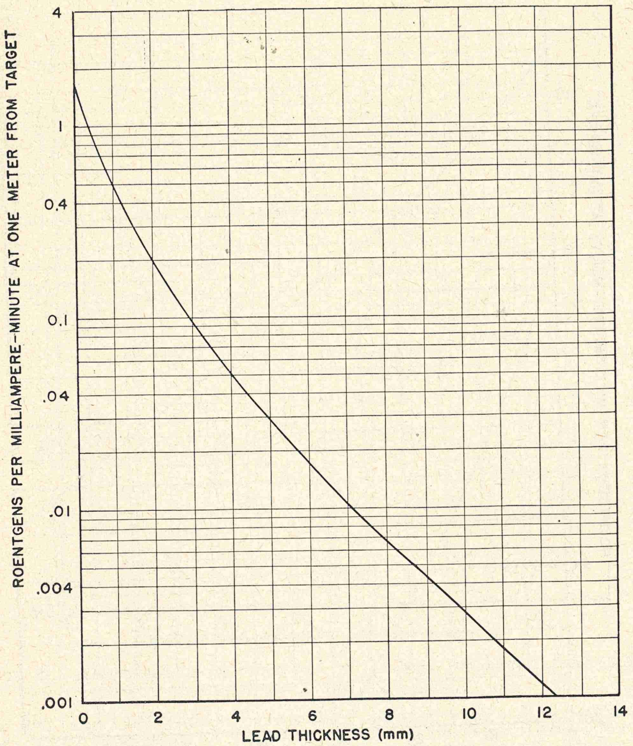

Figure 4. *Attenuation in lead of X-rays produced by a potential of 400-kilovolts peak.*

The curves were obtained with a half-wave generator and with a 90-degree angle between the electron beam and the axis of the X-ray beam. The filter was 0.4 millimeter of tin, 0.75 millimeter of copper, 2 millimeters of aluminum, plus the inherent filtration of the tube. (C. B. Braestrup, 1948).

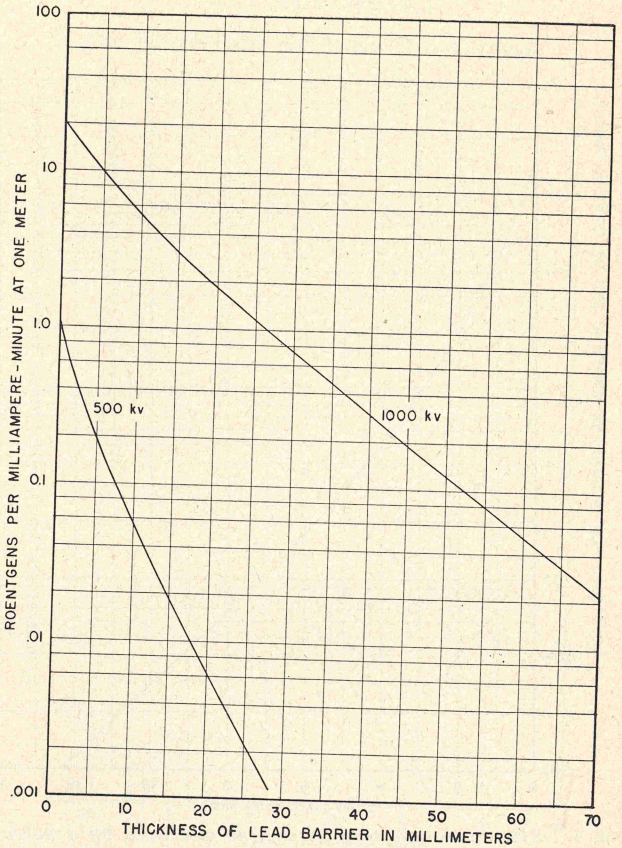

FIGURE 5. *Attenuation in lead of X-rays produced by potentials of 500- and 1,000-kilovolts.*

The curves were obtained with a direct-current generator and with an angle of zero degree between the electron beam and the axis of the X-ray beam. The inherent filtration was 2.8 millimeters of tungsten, 2.8 millimeters of copper, 2.1 millimeters of brass, and 18.7 millimeters of water. (H. O. Wyckoff, R. J. Kennedy, and W. R. Bradford, 1948).

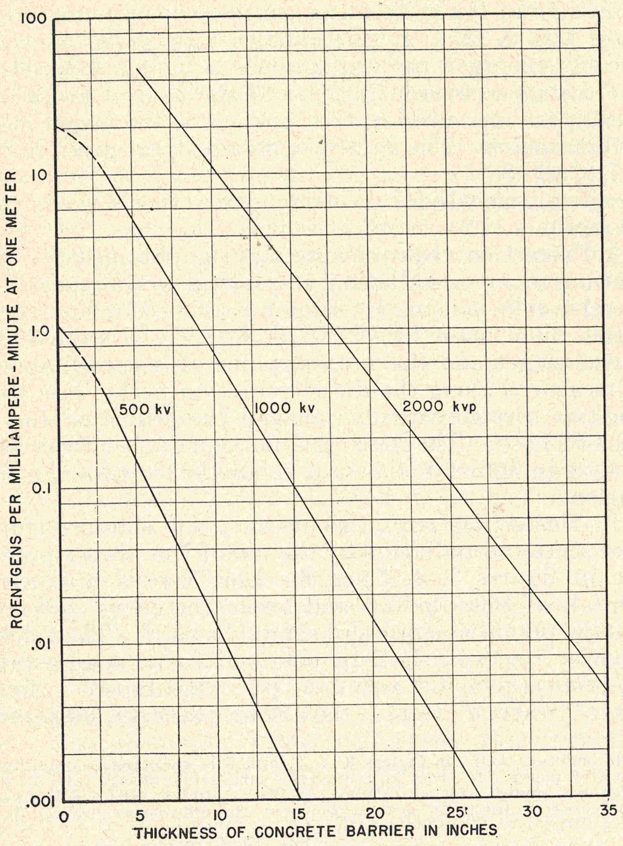

FIGURE 6. *Attenuation in concrete of X-rays produced by potentials of 500 to 2,000 kilovolts.*

The 500- and 1,000-kilovolt curves were obtained with a direct-current generator (H. O. Wyckoff, R. J. Kennedy, and W. R. Bradford, 1948); the 2,000-kilovolts peak was obtained with a resonance generator (G. Singer, C. B. Braestrup, and H. O. Wyckoff, 1946). All data were obtained with an angle of zero degree between the electron beam and the axis of the X-ray beam. The filter at 500 and 1,000 kilovolts was 2.8 millimeters of tungsten, 2.8 millimeters of copper, 2.1 millimeters of brass, 18.7 millimeters of water, and at 2,000-kilovolts peak was 1.6 millimeters of tungsten, 5.1 millimeters of copper, and 6.8 millimeters of water. If the density of the concrete used in an installation is different from that of the above curves (147 pounds per cubic foot), the abscissa should be corrected by a factor of 147 divided by the density of concrete used.

19.1. Use of Curves.

a. Requirements for primary protective barriers. The thicknesses required for primary protective barriers may be obtained from the attenuation curve for the potential producing the X-rays at the dosage rate given by D^2/ma $(9.66)10^{-6}$ roentgen per milliampere minute at 1 meter.[18] D is the distance between target and the nearest point of occupied space measured in feet, and ma is the target current in milliamperes. The values, so obtained, are given in tables 5, 6, 7, 8, and 9.

b. Requirements for secondary protective barriers (1.25). (See sections 12.2c, 12.2d, and 12.2e).

(1) Protection requirements may be obtained for direct radiation in an installation employing a therapeutic-type protective tube housing by using a barrier to reduce the dosage rate by a factor of $(1.72/D^2)\times 10^3$.[19] D is the distance between target and the nearest point of occupied space, in feet, measured along the direct-radiation path. For a diagnostic-type protective tube housing the reduction factor is $(1.72\times 10^2)/D^2$. The "straight" portion of the proper potential curve in figures 3, 4, 5, or 6, should be used for this determination.

(2) Protection requirements may be obtained for 90-degree scattered radiation by the use of the proper potential curve in figures 3, 4, 5, or 6. For X-rays produced by potentials of 500 kilovolts and lower, the curve corresponding to the potential employed should be used. The thickness of barrier required shall be obtained for a dosage rate of $(d^2\ D^2/ma)(8.98)10^{-4}$ roentgen per milliampere minute at 1 meter,[20] where d (feet) is the distance between scatterer and

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[18] The ordinate unit for figures 3, 4, 5, and 6 is roentgens per milliampere minute at 1 meter. In order to reduce the permissible dosage rate, 1.04×10^{-4} roentgen per minute, for a distance, D (feet), and a target current of ma (milliamperes) to the units used on the curve, the following expression is used:

$$\frac{D^2}{ma}\,\frac{(1.04\times 10^{-4})}{(3.28)^2} \text{ or } \frac{D^2}{ma}(9.66)10^{-6}.$$

3.28 is the number of feet per meter.

[19] The dosage rate of the direct radiation from a therapeutic-type protective tube housing is 1 r per hour at 1 meter. This is 160 times the permissible dosage rate at this distance. At a distance of D (feet) it is

$$\frac{160}{D^2}(3.28)^2 \text{ or } \frac{1.72\times 10^3}{D^2}.$$

As the diagnostic-type protective-tube housing permits a direct radiation of only 0.10 roentgen per hour at 1 meter, the barrier must reduce this dosage rate by only $1.72\times 10^2/D^2$.

[20] The permisible dosage rate, 1.04×10^{-4} roentgen per minute, is assumed for the position in occupied space. Using the 0.1-percent factor for the dosage rate of the scattered radiation compared to the useful beam and the inverse-square reduction in dosage rate for the distance between the scatterer and occupied space as well as the distance between target and scatterer one obtains:

$$\frac{d^2D^2(1.04)10^{-1}}{(3.28)^4\,ma} \text{ or } \frac{d^2D^2(8.98)10^{-4}}{ma}$$

roentgen per milliampere minute at 1 meter. This dosage rate of the useful beam at 1 meter is required to obtain the permisible dosage rate at the point of occupied space considered.

the nearest point of occupied space, D (feet) is the distance between target and scatterer, and ma is the target current in milliamperes. For X-rays produced by potentials of 1,000 kilovolts, the thickness required should be obtained from the 500-kilovolt curve at a dosage rate of $(d^2D^2/ma)\times (8.98)10^{-5}$ roentgen per millimeter minute at 1 meter[21] and for those of 2,000 kilovolts at (d^2D^2/ma) (1.50) 10^{-5}.

c. *Example:* Find the primary and secondary protective barrier concrete thickness required for a therapeutic X-ray tube operating at 1,000 kilovolts and 1 milliampere. The distance between the target and nearest point of occupied space is 20 feet for the useful beam and 15 feet for both the direct radiation and the scattered radiation. The distance between target and scatterer may be assumed to be 3 feet.

(1) The thickness of the primary protective barrier required is obtained from table 8. It is 25 inches of concrete.

(2) For direct radiation, using the formula given in section 19.1b(1), one obtains a required reduction factor of 7.6. From the 1,000 kilovolt curve of figure 6, it is evident that such a reduction is obtained for a barrier thickness of $26.5-21.5$ inches, or 5 inches of concrete.

(3) For 90-degree scattered radiation, using the formula in section 19.1, b, (2), one obtains $(3^2\times 15^2/1)(8.98)10^{-5}$, or 0.182 roentgen per milliampere minute, at 1 meter. The 500-kilovolt curve of figure 6 shows that 4.5 inches of concrete are required for this protection.

(4) The secondary protective-barrier thickness is obtained according to the rules of section 12.2c. The half-value layer for section 19.1, c, (2) is 1¾ inches and for 19.1, c, (3) is 1½ inches. As the difference between the requirements of 19.1, c, (2) and 19.1, c, (3), 0.5 inch of concrete is not greater than three times 1¾ inches, one half-value layer should be added to the 5.0 inches to obtain the secondary protective barrier thickness. The result is 6¾ inches.

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[21] The numerical constants are changed as the dosage rate for 1,000 kilovolts is 10 times that for 500 kilovolts, and for 2,000 kilovolts it is 60 times that for 500 kilovolts.

20. Approximate Lead Thicknesses Required To Reduce Radiation Dosage Rate to 5 Percent of Useful Beam

TABLE 3.

Kilovolts	50	75	100	150	200	250	400	500	1,000	2,000
Lead thickness (mm)	0.1	0.3	0.4	0.7	1.0	1.3	3.0	7	32	50

21. Distance Protection

TABLE 4

Target current	Distance[1] for—									
	50 kv	75 kv	100 kv	150 kv	200 kv	250 kv	400 kv	500 kv	1,000 kv	2,000 kv
ma	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*
0.005	15	20	25	20	25	25	25	30	90	195
.01	20	25	30	30	35	35	35	40	115	240
.025	30	40	45	45	50	55	55	60	175	370
.05	40	50	60	60	65	70	70	75	220	460
.1	50	70	80	80	90	95	95	110	275	540
.25	70	95	115	115	125	135	135	155	380	720
.5	85	115	145	145	165	170	170	200	460	850
1	100	145	180	185	205	215	215	255	550	980
2	115	175	220	225	255	270	270	320	640	1,080
2.5	120	185	235	245	270	285	295	340	690	----
5	140	220	280	295	330	350	360	410		----
10	160	250	330	350	390	420	---	---	----	----
15	175	270	355	390	430	460	---	---	----	----
20	185	290	380	410	460	490	---	---	----	----
25	195	300	390	420	480	510	---	---	----	----

[1] These distances were computed by taking into account distance and air absorption. The air absorption was determined by assuming the radiation was monochromatic and of double the minimum wavelength of the polychromatic radiation given off by the tube at the indicated potential. The filtrations assumed were the same as the curves of figs. 3, 4, 5, and 6.

21.1. Table 4 gives directly the distance at which the dosage rate of the useful beam is 0.104 milliroentgen per minute (permissible dosage rate) if no absorbing material other than air is in the beam.

21.2. The distance protection required for 90-degree scattered radiation may be obtained from table 4, provided the distances between the target and scatterer is not large. For X-ray-tube potentials of 500 kilovolts and under, such distances may be obtained for the column corresponding to the potential on the X-ray tube and the row corresponding to $0.001/D^2$ of the true target current. For X-ray-tube potentials above 500 kilovolts, the 500-kilovolt column should be used. At a tube potential of 1,000 kilovolts the row equal to $0.01/D^2$ milliampere[22] should be used, and at a tube potential of 2,000 kilovolts the row equal to $0.06/D^2$ milliampere should be used, where D is the distance between the target and scatterer, measured in meters.

21.3. The target distance required for protection against direct radiation is 12.7 meters (approximately 42 feet) for a therapeutic-type protective tube housing and 4 meters for a diagnostic-type protective tube housing.

21.4. *Example*: Find the distance required for protection against the useful beam and 90-degree scattered radiation for an X-ray tube operating at 1,000 kilovolts and 1 milliampere, with a therapeutic-type protective tube housing. The distance between scatterer and target may be assumed to be 1 meter.

a. The distance protection required for the useful beam is found in table 4 at the intersection of the 1,000-kilovolt column and the 1-milliampere row. The distance between target and occupied space indicated there is 550 feet.

b. The distance protection required for 90-degree scattered radiation is found in table 4 at the intersection of the 500-kilovolt column and the 0.01 milliampere row. Such protection may be obtained if the personnel are at least 40 feet from the scatter.

22. Primary Protective Barrier Requirements

All barrier requirements are computed for a distance from the barrier of at least 7.5 inches. At smaller distances the requirements may be several half-value layers larger. These tables are computed from the curves of figures 3, 4, 5, and 6.

If the X-ray tube current is two times as large as that given in the table, one half-value layer shall be added to the barrier requirement (if four times, two half-value layers added, and if ½, one-half-value layer subtracted, etc.).

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[22] The value of the constants is changed as the dosage rate at 1,000 kilovolts is 10 times that for 500 kilovolts, and at 2,000 kilovolts it is 60 times that at 500 kilovolts.

Table 5. *Primary protective-barrier requirements for 10 milliamperes at the pulsating potentials*[1] *and distances indicated*

Target distance	Lead thickness with peak of—				
	75 kv	100 kv	150 kv	200 kv	250 kv
ft	*mm*	*mm*	*mm*	*mm*	*mm*
2	2.2	3.4	4.3	6.7	11.8
3	2.0	3.1	4.0	6.2	10.9
5	1.7	2.7	3.6	5.5	9.6
8	1.5	2.4	3.2	4.8	8.5
10	1.3	2.2	3.0	4.5	8.1
15	1.1	1.9	2.6	4.0	7.1
20	1.0	1.7	2.4	3.6	6.4
50	0.5	1.1	1.7	2.4	4.3
Approximate half-value layer	.2	0.2	0.3	0.5	0.8

[1] Direct-current potentials require the order of 10 percent greater thickness than those given here for pulsating potential.

Table 6. *Primary protective-barrier requirements for 400-kilovolts peak pulsating potential with reflection target*

Target distance	Lead thickness with target current of—		
	1 ma	3 ma	5 ma
ft	*mm*	*mm*	*mm*
5	16.5	20	22
8	14.0	17.0	18.5
10	12.5	15.5	17.0
15	11.0	13.5	14.5
20	9.5	11.5	13.0
50	5.5	8.0	9.0
Approximate half-value layer	2.0	--------	--------

Table 7. *Primary protective-barrier requirements for 500-kilovolt constant potential with transmission target*

Target distance	Barrier thicknesses with target current of—					
	1 ma		3 ma		5 ma	
	Lead	Concrete[1]	Lead	Concrete[1]	Lead	Concrete[1]
ft	*mm*	*in.*	*mm*	*in.*	*mm*	*in.*
5	36	18.0	42	20.5	44	21.5
8	31	16.0	37	18.5	39	19.5
10	29	15.0	35	17.5	37	18.5
15	25	13.5	31	16.0	33	17.0
20	22	12.5	28	14.5	30	16.0
50	14	8.5	19	11.0	21	12.0
100	8	6.0	13	8.0	15	9.5
Approximate half-value layer	----	------	3.0	1.5	----	------

[1] The density of this concrete is 147 pounds per cubic foot.

Table 8. *Primary protective-barrier requirements for 1,000-kilovolt constant potential with transmission target*

Target distance	Barrier thicknesses with target current of—					
	1 ma		2 ma		3 ma	
	Lead	Concrete[1]	Lead	Concrete[1]	Lead	Concrete[1]
ft	*mm*	*in.*	*mm*	*in.*	*mm*	*in.*
5	123	30.5	131	32.5	136	33.5
8	113	28.0	120	29.5	125	30.5
10	107	27.0	115	28.5	120	29.5
15	97	24.5	105	26.5	110	27.5
20	91	23.0	99	25.0	103	26.0
50	69	18.5	77	20.5	82	21.0
100	53	15.0	61	17.0	66	18.0
Approximate half-value layer	----	------	8	1.8	----	------

[1] These concrete thicknesses are for a concrete density of 147 pounds per cubic foot.

TABLE 9. *Primary protective-barrier requirements for 2,000-kilovolt peak pulsating potential with transmission target*

Target distance	Concrete thicknesses [1] with target current of—		
	0.5 ma	1.0 ma	1.5 ma
ft	*in.*	*in.*	*in.*
5	42. 5	45. 0	46. 5
8	39. 5	42. 0	43. 5
10	38. 5	40. 5	42. 0
15	35. 5	38. 0	39. 5
20	34. 0	36. 0	37. 5
50	28. 0	30. 0	31. 5
100	23. 5	25. 5	27. 0
Approximate half-value layer	--------	2. 3	----------

[1] These concrete thicknesses are for a concrete density of 147 pounds per cubic foot.

23. Other Dangers

There are a number of dangers that are not directly related to X-ray protection, but which must be dealt with in an X-ray installation. These items are already covered by codes or instruction books, to which references are given below. It is recommended that such literature, where pertinent, be available at the X-ray installation.

23.1. Fire hazard.

a. All unexposed X-ray films now available are of the cellulose-acetate type. Such films constitute no greater fire hazard than ordinary newspaper in the same form. Storage of nitrocellulose films shall be in accordance with the regulation of July 15, 1930, of the National Board of Fire Underwriters for the Storage and Handling of Photographic and X-ray Nitrocellulose Film.

b. The type of fire extinguisher to be used in the vicinity of electrical installations is covered in National Board of Fire Underwriters pamphlet No. 10, "First Aid Fire Appliances."

23.2. First-aid advice, including methods of resuscitation for electrical shock, is contained in "First-Aid Textbook", American Red Cross, Washington, D. C.

a. For equipment in which Freon is used for insulation, it may be desirable to have available a gas mask suitable for a phosgene atmosphere. Such masks are covered in National Bureau of Standards Handbook 24, "American Standards Safety Code for the Protection of Head, Eyes, and Respiratory Organs."

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Submitted for the National Committee on Radiation Protection,

LAURISTON S. TAYLOR, *Chairman.*

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